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THE EVIDENCE OF THREE DISTINCT GLACIAL EPOCHS IN THE PLEISTOCENE HISTORY OF THE SAN JUAN MOUNTAINS, COLORADO[1]

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AND
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Each of the six advances of ice from the Labrador and Keewatin centers during Pleistocene times was presumably accompanied by a similar formation and advance of glaciers in the Cordilleran region of North America. Each of the five interglacial intervals which have been recognized in the Mississippi Valley must have been accompanied by a shrinkage of the ice in the mountains which may or may not have resulted in complete deglaciation of the mountain areas. It is also evident that certain mountain groups, depending largely upon the latitude and altitude, may have been affected by less than the full number of ice formations and advances. Examples have been pointed out among the Uinta Mountains where certain basins that were glaciated during the earlier of two epochs were not occupied by ice during the later glacial epoch.[2]

The difficulty of recognizing and differentiating glacial deposits of distinct epochs in the mountains is somewhat greater than that of identifying deposits of successive continental ice sheets. Each ice advance in a single mountain valley would presumably remove most if not all of the deposits of a preceding advance. In most cases the erosive action of the ice formed during the epoch of maximum glaciation would effectually destroy all evidence of previous glacial epochs. In all cases of distinct glacial epochs which have as yet been worked out among the mountains the morainic materials of the earlier epochs were deposited beyond the reach of all succeeding ice advances.

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[1] Published with the permission of the Director of the United States Geological Survey.

[2] W. W. Atwood, *U.S. Geol. Survey, Prof. Paper 61* (1909), 13, 14, 22, 58.

In each of the higher ranges of the North American Cordillera evidence of recent glaciation is abundant, but in only a few of the ranges have glacial studies been prosecuted with sufficient detail to demonstrate distinct glacial epochs.

In the Bighorn Mountains of Wyoming evidences of two glacial epochs have been found.[1] The earlier of these was slightly more extensive than the later and the time interval between the two must have been considerable. In addition to these two drift deposits certain large bowlders were noted as suggestive of a possibly still older and more extensive epoch of glaciation in that range.

In the Sawatch range similar facts to demonstrate two glacial epochs have been ascertained.[2]

In this region a deposit of huge bowlders has been reported beyond the earliest known glacial drift, and in such relations to the present topography that if proven to be of glacial origin they would demonstrate a third and much older glacial epoch.

In the Uinta and Wasatch mountains morainic deposits of two well-defined epochs of glaciation have been identified,[3] and in the Front range of the Rockies the drift deposits have likewise been referred to two glacial epochs.[4]

In the San Juan Mountains of southwestern Colorado the effects of glaciation have been noted by many observers. In the Telluride, La Plata, Silverton, Needle mountains, and Rico folios evidence of the recent glaciation is presented, and reference is made to certain gravel deposits suggestive of glaciation in more remote Pleistocene times. Satisfactory evidence of an earlier epoch of glaciation was found in the progress of the field work for the Ouray folio.[1] It is noteworthy that these deposits on the north side of the range which were undoubtedly formed during an epoch of glaciation preceding the last occupation of this range by ice are apparently of greater age than those made by the "earlier ice" of the mountain groups cited above. They are in harmony with the scattered deposits found in the Bighorn and Sawatch ranges which suggested a third and still earlier glaciation, rather than with the earlier of the two well-defined epochs which have been noted in several of the Cordilleran mountain groups. A fuller statement regarding these deposits will be given later in this paper. More recently, in the Engineer Mountain quadrangle of the San Juan Mountains, evidence of two glacial epochs has been recognized.[2]

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[1] Salisbury and Blackwelder, *Jour. Geol.*, XI (1903), 216–23.

[2] Capps and Leffingwell, *Jour. Geol.*, XII (1904), 698–706; Capps, *U.S. Geol. Survey Bull. 386* (1907); Westgate, *Jour. Geol.*, XIII (1905), 285–312.

[3] W. W. Atwood, *U.S. Geol. Survey, Prof. Paper 61* (1909).

[4] S. H. Ball, *U.S. Geol. Survey, Prof. Paper 63* (1908), 83–86; F. L. Ransome, *U.S. Geol. Survey, Prof. Paper 75* (1911), 72–79.

Work upon which the present paper is based.—In 1910 the glacial deposits of the La Plata, Animas, Florida, Vallecito, and Pine valleys on the southern and southwestern slopes of the San Juan range were studied in detail and these studies revealed the evidence of two distinct glacial epochs.[3]

In 1911 similar studies in the valleys of Weminuche and Huerto creeks and the Piedra River, on the southeastern, of the Rio Grande on the eastern, and of the Uncompahgre and Dallas, on the northern slopes of the range, have resulted in the finding of evidence which will be presented as proof of three distinct glacial epochs in the history of this mountain group.

Nomenclature.—It is not as yet possible definitely to correlate the glacial epochs among the mountains with those of the continental ice sheets, and even if such a correlation could be correctly made it may prove desirable to have different names for the epochs associated with the two types of glaciation which existed on this continent during the Pleistocene period. Throughout this paper the three epochs now known to have existed in the San Juan area will be referred to by the names which were applied and used in the

[1] Howe and Cross, *Bull. Geol. Soc. Am.*, XVII (1905), 251–74; Cross and Howe, *U.S. Geol. Survey, Folio 153* (1907).

[2] A. D. Hole, *U.S. Geol. Survey, Folio 171* (1910).

[3] W. W. Atwood, *Jour. Geol.*, XIX (1911), 449–53.

progress of the field work. In the selection of the names an attempt has been made to recognize some of the glacial studies which have contributed to the solution of this problem.

The earliest and oldest of the three known glacial epochs is designated the "San Juan glacial epoch"; the intermediate epoch, formerly called the "earlier" or "older," is here called the "Bighorn glacial epoch"; while the most recent and youngest of the three is referred to as the "Uinta glacial epoch."

It is believed that it may also be of advantage to apply names to the interglacial intervals as well, and for that purpose the following names are tentatively proposed: for the interval between the San Juan and Bighorn glacial epochs the term "Uncompahgre interglacial interval" is suggested; and for the interval between the Bighorn and Uinta glacial epochs we may use the term "Animas interglacial interval." These names have been applied because portions of the valleys of the two streams named are good examples of the canyon development accomplished during the interglacial times.

The Pleistocene period in the western mountains would then be subdivided, beginning with the earliest of the known glaciations in that region, as follows:

San Juan glacial epoch.
Uncompahgre interglacial interval.
Big Horn glacial epoch.
Animas interglacial interval.
Uinta glacial epoch.

General features of the San Juan Mountains.—The San Juan Mountains embrace an area of about 3,000 square miles in southwestern Colorado, extending westward from the San Luis Park to within fifty miles of the Utah boundary. North and south the mountainous area varies in width from 25 to 40 miles. The central portion of the region is a group of rugged peaks, many of which are over 14,000 feet in elevation, while the borders of the range slope downward to the plateaus of New Mexico and Utah.

The central mountain mass is formed of igneous rock, both volcanic and intrusive, which during Tertiary times was built up into a great volcanic plateau several thousand square miles in extent. Beneath the volcanics, the sedimentary rocks of Paleozoic and Mesozoic age dip away from the central portion of the region; in a few of the deeper valleys and near the present borders of the volcanic area, the complex of pre-Cambrian sediments, schists, gneisses, and intrusive rocks upon which the Paleozoic and Mesozoic rocks rest, is exposed. About the margin of the range there are some clastic sediments of Tertiary age.

The range has been maturely dissected by the headwaters of four great streams which have attacked it from every side. On the east the Rio Grande, on the south the San Juan, on the west the Dolores, on the north the Gunnison, each with its many tributaries, has penetrated to the very heart of the mountains. The Rio Grande flows to the Gulf of Mexico, while the other three, finding their way across the plateaus through deep canyons, join the Colorado River and thence empty into the Gulf of California. (See Fig. 1.)

The work of each of these stream systems has been greatly influenced during Pleistocene times by the action of glacial ice. Many of the peaks and divides were notably sculptured by ice action and the valleys in the mountains show the effect of the passage of the glaciers through them. On the surrounding mesas and plateaus there are some glacial deposits and in the valleys beyond the base of the range there are many terraces and benches which may be traced upstream to the terminal moraines just within the mountainous region.

The more readily recognized deposits of the two younger epochs will be first described, so that the evidence bearing upon a third and still earlier epoch may be more clearly presented.

The Uinta glacial epoch in the San Juan Mountains.—During Uinta times ice collected at the heads of nearly all of the larger streams in the San Juan area and moved for a greater or less distance into the valleys below. In the heart of the range only the higher peaks and divides were above the glaciers, but as the ice moved outward from the central portion of the range it became concentrated in the larger valleys and left much of the region unglaciated. In each of the valleys thus far studied the glaciers of the Uinta epoch were strictly limited to the valleys and in no case did they extend far beyond the foothills of the range.

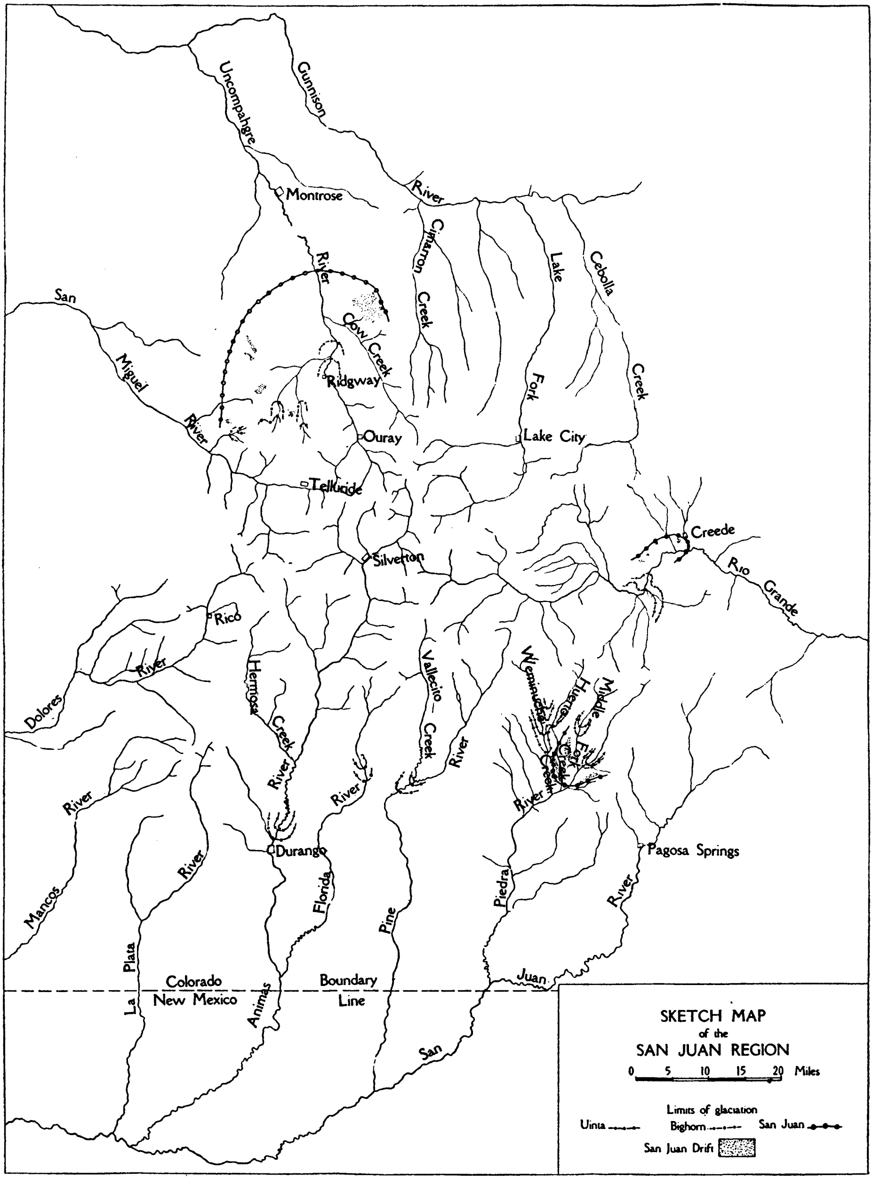

Gunnison
Uncompahgre
River
Montrose
Cimarron
Creek
Lake
Fork
Cebolla
Creek
San
Miguel
River
River
Cow
Creek
Ridgway
Ouray
Lake City
Telluride
Silverton
Creede
Rio
Grande
Rico
Dolores
River
Hermosa
Creek
River
Vallecito
Creek
River
Weminuche
Creek
Huerta
Creek
Middle
Fork
River
River
Mancos
River
Durango
Florida
River
Pine
Piedra
River
Pagosa Springs
La
Plata
Colorado
New Mexico
Animas
Boundary
Line
Juan
San
SKETCH MAP
of the
SAN JUAN REGION
0 5 10 15 20 Miles
Limits of glaciation
Uinta
Bighorn
San Juan
San Juan Drift

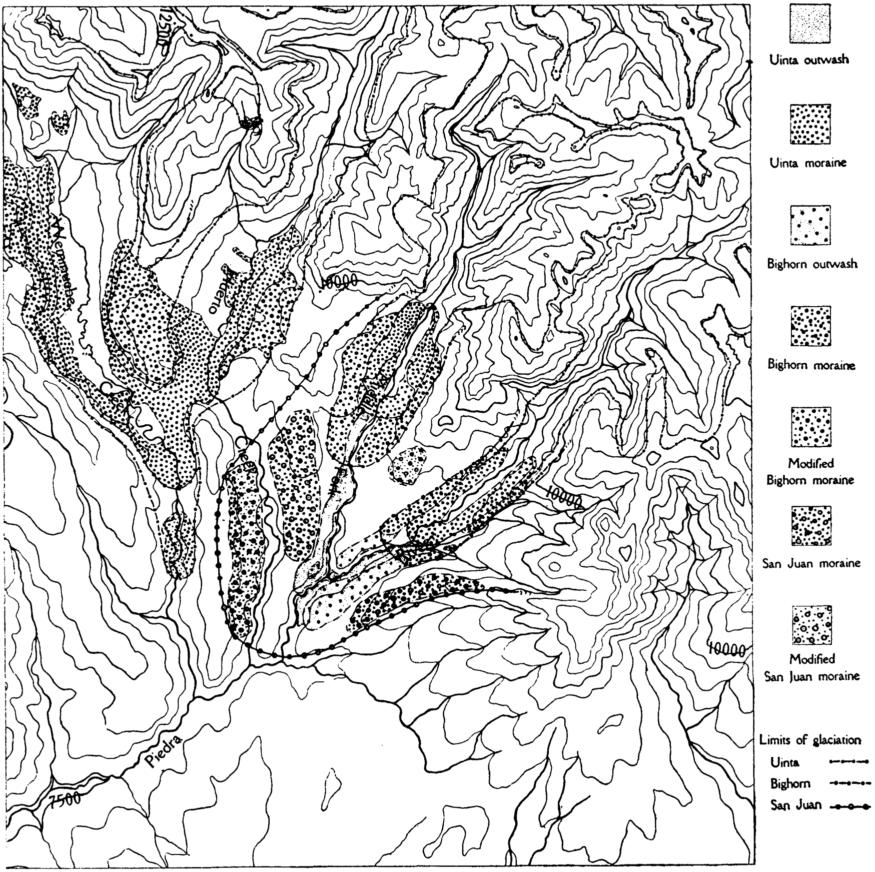
Fig. 1

The largest of the glaciers of this epoch was that which occupied the Animas Valley on the south slope of the range. The gathering grounds for this glacier covered several hundred square miles and it had a length of over fifty miles. The terminal moraine deposited when this glacier was at its maximum extent is near Animas City, two miles north of Durango. This moraine consists of two well-marked ridges swinging across the valley floor in broadly crescentic lines. Downstream from the Animas City moraine there are outwash deposits which extend for many miles. Upon one of the terrace remnants of this outwash is situated the city of Durango. Two slightly different levels appear to have been capped with outwash materials at this time and the uppermost of the two is less than fifty feet above the present stream channel.

Similar but smaller glaciers occupied the valleys of the Florida, Vallecito, and Pine rivers, situated east of the Animas. The terminal deposit of the Florida glacier is in the form of a number of low hills or knolls scattered over the valley floor, while the ice in the other two valleys coalesced and the terminal deposit crosses the valley flat of the Pine River a mile below the junction of the two streams.

Still farther east the four large streams which together form the Piedra River show the results of ice occupancy during the Uinta epoch. The terminal deposits in these valleys are likewise well within the foothill zone and, as shown in Fig. 2, are limited to the immediate valley flats. The streams have cut but narrow channels through these morainal barriers.

Another glacier of considerable size occupied the valley of the Rio Grande, extending from well within the Silverton quadrangle to the eastern margin of the San Cristobal quadrangle. South and southeast from Bristol Head at the lower ends of Middle Creek, Trout Creek, and South River (see Fig. 3) there is a very considerable mass of morainic material deposited from the glaciers which, during Uinta times, filled the four valleys mentioned and united in the Rio Grande Valley. This deposit has a typical morainal topography and must aggregate a thickness of 200 to 300 feet in places. Near the middle of the Rio Grande Valley the material is almost entirely that left by the Rio Grande glacier and it contains great quantities of bowlders of pre-Cambrian rocks—quartzites, schists, gneisses, and granites—which must have been obtained from near the headwaters of the Rio Grande. The débris



Map of the upper Piedra River
Topography from San Cristobal quadrangle and Hayden Atlas·
0 1 2 3 4 5 Miles
Contour interval 500 feet

FIG. 2

transported by the tributary glaciers from the south is largely of volcanic origin.

The third largest glacier of the region during this epoch was that in the Uncompahgre Valley on the north side of the range.

Ice formed in the cirques of the Silverton quadrangle and moved northward by the present site of the city of Ouray to a point fully ten miles downstream from that city where the ice ceased to advance and deposited a remarkable terminal moraine. This is the largest of the terminal moraines as yet described in the San Juan area; it is over 400 feet in height[1] and forms a crescentic ridge across the valley flat just northeast of the village of Ridgway.

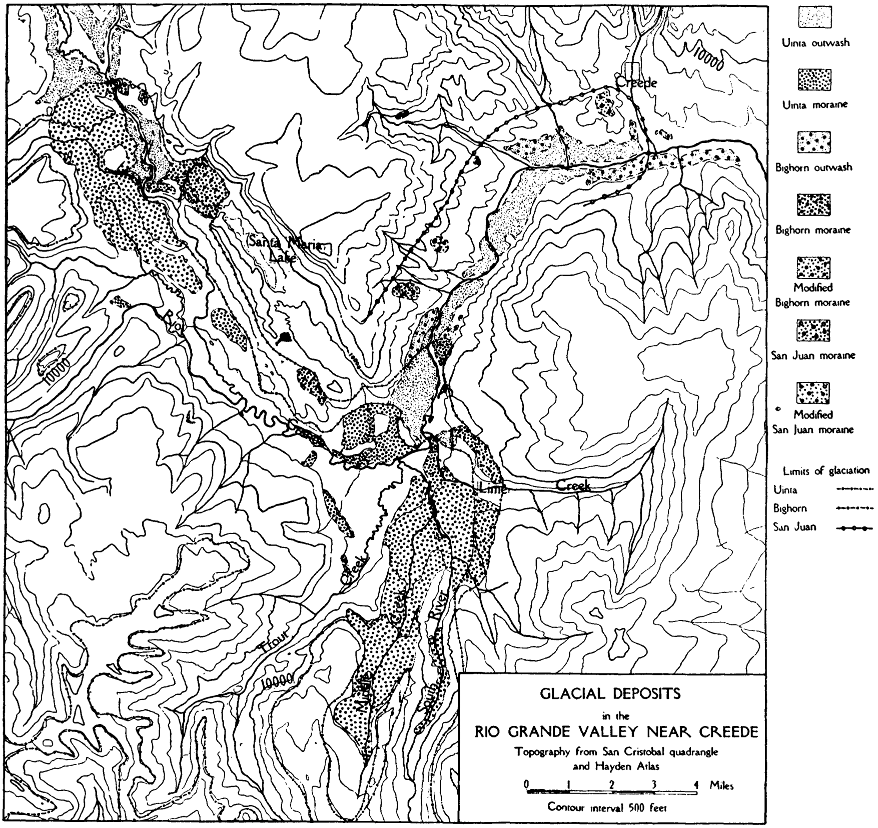


FIG. 3

Near the headwaters of Dallas Creek, a tributary to the Uncompahgre from the west, there were small glaciers during the

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[1] Howe and Cross, *Bull. Geol. Soc. Am.*, XVII (1906), 254–55; Cross and Howe, *U.S. Geol. Survey, Folio 153* (1907), 7.

Uinta epoch. These glaciers formed in the basins near the north base of Mount Sneffels. The terminal moraines of these glaciers are conspicuous masses of drift in the valley and upstream from these moraines there are other glacial deposits.

The extreme recency of the Uinta glaciation is shown in many ways. The materials of the moraines are fresh and unaltered, retaining in many cases polished surfaces and striae. Post-Uinta weathering and stream erosion are of very limited amount as shown not only by the glaciated rock surfaces so numerous in the upper courses of the streams but also by the character of the glacial débris itself. The streams are still engaged in the task of cutting channels through the drift and clearing it away from their courses, while downstream from the terminal moraines the outwash terraces are never more than a few feet above the present stream channels. Most conspicuous of all, as noted by many observers in the western mountains, is the slight modification which the later glacial deposits have undergone. Typical knob and kettle topographies are present in the drift deposits at many places and small lakes occupy many of the undrained depressions.

The Animas interglacial interval.—The time interval immediately preceding the epoch of glaciation which has just been described was a time of active erosion in the San Juan area. The streams were vigorously engaged in the work of lowering their channels, and canyons were cut beneath the level of the broad valley floors which had received the deposits of the next earlier or Bighorn glacial epoch. The Animas River lowered its channel during this time by more than 300 feet, near the city of Durango, while the valley deepening in the Uncompahgre Valley was even greater. This change in work from that of lateral planation in progress during the Bighorn glacial epoch, to that of active downward cutting, may be attributed to the clearing of the waters following the melting away of the Bighorn ice, but it is probable that this interval of canyon cutting is an evidence of mountain growth during or immediately following the Bighorn epoch. A slight renewal of the domal uplift movements that seem to have affected this region several times during Tertiary and Quaternary times would have rejuvenated streams radiating from the central portion of the dome. Further physiographic studies in the range will probably yield conclusive data on this problem.

The Bighorn glacial epoch.—Beyond the limits reached by the Uinta ice at its maximum extent there are, in each of the valleys noted above, deposits of glacial drift which prove the presence in these valleys of ice of an earlier epoch. These drift deposits are, in most cases, remnants of the terminal moraines of the next earlier, or Bighorn, glaciers and are found from one to three miles downstream from the Uinta terminal moraines. The greater size of the Bighorn glaciers is also evidenced in some of the valleys by the presence of remnants of lateral moraines on valley slopes at greater elevations than those of the Uinta epoch at those localities.

The remnants of the terminal moraines deposited by the Bighorn ice are in each case situated on rock benches which vary in elevation up to something more than 300 feet above the present stream channels. This relationship is well shown in the Animas Valley where the Bighorn moraine is found on the very prominent rock bench east of the city of Durango and at an elevation of more than 300 feet above the present valley bottom. The northern portion of this rock terrace is heavily mantled with the morainal débris, while downstream from the front of the moraine the terrace is capped with outwash gravels having in places a thickness of at least thirty feet. In each of the main canyons east of the Animas similar conditions obtain.

At the time of the advance of the Bighorn ice Huerto Creek (see Fig. 2) was tributary to the Weminuche through the low sag, now partially filled with Uinta drift, just south of the San Cristobal quadrangle, and the ice in the two valleys, coalescing at this point, moved down Weminuche Creek a distance of three miles below the lower limits of the Uinta drift in that valley. Remnants of the terminal moraine deposits at this point are found on a rock bench 75 feet above the present stream. The small amount of post-Bighorn Valley cutting here as compared with that in the Animas Valley is probably due to several causes. The diversion of the headwaters of Huerto Creek, which will be accounted for later, robbed the Weminuche of nearly half of its former volume; the Animas is a very much larger stream than the Weminuche and is capable of doing much more work in the same time; the domal movement which caused the renewal of down cutting during the Animas interglacial epoch may have been differential. Eastward from Huerto Creek two other canyons have been studied in which Bighorn glacial deposits have been recognized.

In the Rio Grande Valley the deposits of Bighorn drift are found extending downstream about two miles below the Uinta terminal moraine and are banked against the eastern wall of the Rio Grande Valley a short distance up Lime Creek (see Fig. 3) and southward across the latter to the eastern wall of South River Valley. The conspicuous ridge southeast from Bristol Head on the floor of the Rio Grande Valley, which stopped the further advance of the Uinta ice at that point, is also capped with drift bowlders dropped upon it when it was overridden by the more extensive Bighorn ice. Downstream from the terminal moraine in this valley there are very notable outwash terraces of considerable extent with an elevation of nearly a hundred feet above the present stream channel.

In the Uncompahgre Valley on the north slope of the range similar relations exist between the drift of the two later epochs of glaciation. On the extreme southeast corner of the Uncompahgre plateau near Dallas there is a glacial drift deposit capping the mesa. The bowlders range in size up to three feet in diameter and comprise quartzite, sandstone, shale, tuff, and a variety of volcanic rocks. Some of the stones in this deposit are striated. In this deposit there are also large angular blocks of Dakota sandstone which were certainly not carried by water. They are at present in the midst of the bowlder deposit some hundred feet above the Dakota surface beneath them. The Dakota surface rises gently toward the west and forms the Uncompahgre plateau. The angular blocks could not have attained their present position by sliding or by stream action. They show no signs of stream wear. Up the Uncompahgre canyon the nearest Dakota outcrop is several miles distant, and the only agent that was capable of gathering, transporting, and depositing these blocks in their present position was glacial ice. This fact, combined with the variety of bowlders, their wear and striations, is adequate proof of the glacial origin of this deposit although it has lost its morainal topography. Since this deposit is on a rock bench several hundred feet above the valley flat and downstream from the Uinta terminal moraine has lead to the interpretation that it is of Bighorn glacial age. Directly across the valley on the hills east of Dallas there are other drift deposits with weak morainal topography which have also been interpreted as remnants of the Bighorn drift. Downstream from these patches of Bighorn moraine there are several remnants of the outwash materials from the ice of this epoch. These outwash gravels cap rock benches at elevations of 300 to 500 feet above the present channel of the Uncompahgre River.

Downstream from the Uinta moraines in the headwaters of Dallas Creek there are remnants of an older series of moraines which have been interpreted as of Bighorn glacial age (see Fig. 4). Associated with these deposits there are still remaining some outwash materials which are believed to have been deposited at the time the moraines were laid down.

Although the glaciers of the Bighorn epoch were as a rule slightly longer than those of the Uinta epoch, in no case did they extend beyond the foothill zone surrounding the range or override the walls of the canyons very far so as to spread out over the bordering lands. The Bighorn epoch glaciers were all of the valley type. The valley trains of the Bighorn epoch were of greater extent than those of the later epoch, and the gravel-capped terraces which are remnants of the Bighorn valley floors may be traced for several miles down each of the larger streams radiating from the range.

The amount of valley cutting beneath the level upon which the Bighorn deposits were laid down was much greater than that which has been accomplished since the last retreat of the ice. The length of the Animas interglacial interval, which immediately preceded the Uinta glaciation, was certainly several times as long as the time since the last melting away of the ice.

The Uncompahgre interglacial interval.—Adjacent to the range on the south there are extensive bowlder-capped mesas high above the outwash material of the Bighorn epoch. The Florida and Fort Lewis are good examples of such mesas. Similar gravel-capped elevations have been noted at many places about the range, and in the Ouray quadrangle such gravel cappings have been mapped as "Earlier Terrace Gravels."[1]

The mesas slope away from the mountains with gradients of 150 to 250 feet per mile; their surfaces are from 500 to 1,000 feet above the present valley flats, and in each case they are at elevations 50 to 200 feet above the adjacent terraces which bear the Bighorn outwash gravels. Wherever it has been possible as yet to observe their relations to remnants of San Juan drift it has been noted that

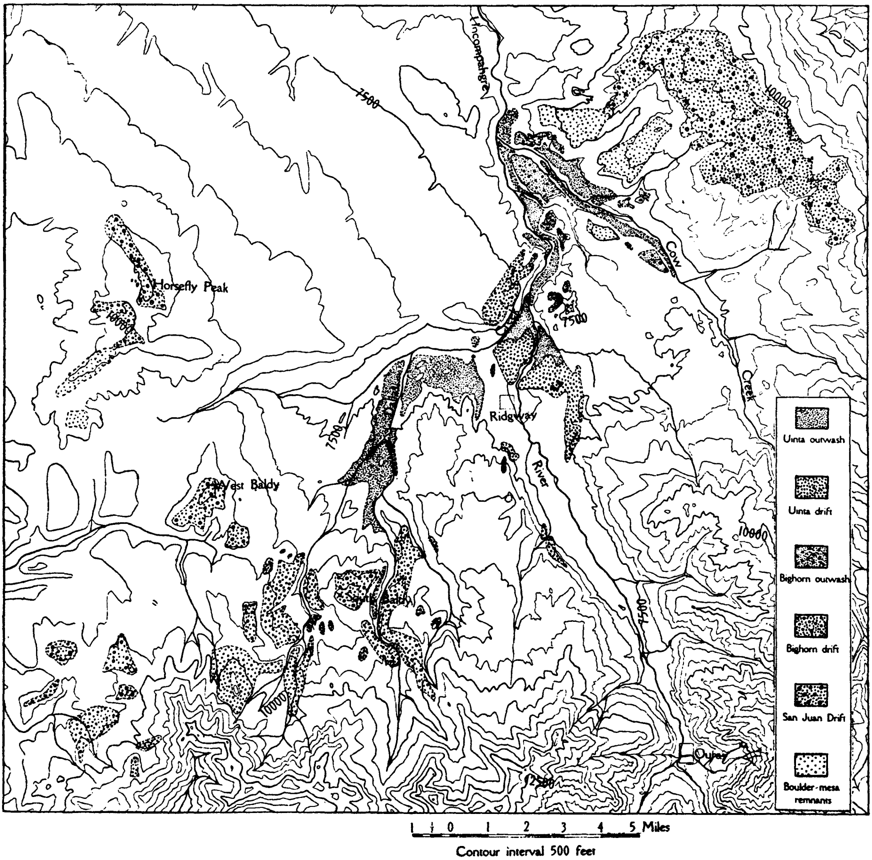

FIG. 4.—Glacial deposits at the northwest margin of the San Juan Mountains. Topography from the Montrose Quadrangle.

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[1] Cross and Howe, *U.S. Geol. Survey, Folio 153* (1907).

the mesa surfaces are cut into and below the elevations now mantled with the drift of that, the oldest known, glacial epoch. The bowlder-gravels capping the mesas may be found to be, in parts outwash materials from the early glaciers, and, in part, remnants of a widespread deposit made by the larger streams during and perhaps immediately following the San Juan glacial epoch. They may belong in part to the Uncompahgre interglacial epoch.

Some time after the retreat of the San Juan ice the streams began to erode their channels vigorously in the mountainous portion of the area. Much of the material removed from the upper courses of the streams was deposited as great alluvial fans on the bordering plateaus. This process of canyon deepening in the mountains continued until much of the San Juan area was skirted by a piedmont alluvial plain sloping gently away from the central mountain region.

The dissection of these bowlder-capped mesas began as the effects of rejuvenation advanced upstream through the bordering plateau country, and continued until the inauguration of the Bighorn glacial epoch, when the streams again became heavily loaded with débris and began to aggrade their valleys.

The distribution of the deposits that have been interpreted as belonging to the San Juan glacial epoch is such as to indicate with certainty that the great canyons through which the glaciers of the two later epochs moved did not exist as deep troughs at the time of the earliest known or San Juan epoch. Deposition of bowlder-gravels may have characterized the earlier part of the Uncompahgre interval, but it is evident that before the close of the interval great canyons had been developed. This interval was certainly much longer than the Animas interglacial interval and it may have been marked by many changes in physiographic conditions which have not as yet been determined.

The valley forms suggest that the streams had reached a temporary base level and had somewhat widened their valleys by lateral planation in the lower country before the formation of the Bighorn glaciers. The rock benches which are now capped with Bighorn moraine and outwash were then the floors of the valleys.

The San Juan glacial epoch.—Evidence bearing on a third and much earlier glacial epoch has now been secured from three widely separated portions of the range (1) near the southeast margin in the valleys of the Piedra and certain of its tributaries, (2) at the eastern side of the range in the Rio Grande Valley, and (3) at the northwest in association with the valley of the Uncompahgre and the plateau of the same name. The first suggestion that there was evidence of a third and much earlier epoch of glaciation in this range than had been determined in the Cordilleran region of North America was secured from the paper by Howe and Cross, so often referred to above.[1] From an inspection of the maps it appeared that if the mantling material of Horsefly Peak was indeed glacial that it must belong to an epoch of glaciation far removed in time from the known glacial epochs of the western mountains. The first determination by the present authors of three distinct epochs was, however, made near the headwaters of the Piedra River. In that region, on the intervalley areas, high above the present streams and beyond the terminal moraines of the two later epochs, there are much older glacial deposits. The distribution of these deposits has been indicated on Fig. 2.

The morainic deposits on the west side of Huerto Creek, a few miles above the Piedra, are, in part, fully 1,000 feet above the Huerto stream channel. They mantle the slope toward the stream in great landslide masses which appear to have come down in very recent times. In this deposit there are bowlders up to 9 feet in diameter and striated material is not uncommon. On the ridge between Huerto and Spring creeks the ancient glacial bowlders occur in abundance and in association with them there is a considerable body of finer drift. Some of the stones in this drift are striated. The deposit on the west side of Huerto Creek appears to have come from the headwaters of the Piedra to the north eastward, and it is inferred from the relationship of these deposits, from the absence of the marks of glaciation in Huerto Creek canyon, and from the distribution of other deposits interpreted as of the same age, that the ice which left these deposits advanced over a surface which corresponded to the elevation of the intervalley ridges, and that the thousand-foot canyon of Huerto Creek has been excavated since the melting away of that ice.

[1] *Bull. Geol. Soc. Am.*, XVII (1905), 251–74.

Another large remnant of the San Juan drift occurs on a ridge 1,000 feet above the Piedra and on the south side of that valley. Many of the bowlders in this deposit range from 5 to 10 feet in diameter and a few are known which reach 25 feet in diameter. As the dissection of the country has progressed since the San Juan glacial epoch these bowlders have rolled down the valley slopes.

From the distribution of these deposits the San Juan ice in this portion of the range must have been a large piedmont glacier which extended at least six miles beyond the mountains and had an areal extent on the lowlands of at least 30 square miles. The ice of Middle Fork, the Piedra, and several smaller canyons appears to have united to form this ancient glacier. The relief in this region during the San Juan epoch must have been much less than that of today.

The complete physiographic map of this region has not been completed because of the need of a good topographic base, but it appears from an examination of the region that the San Juan glacial deposits are above and older than the bowlder mesa horizon, which it is believed has been correctly determined in this outlying country.

The oldest drift yet found in the valley of the Rio Grande occurs on the north side of the valley high above the stream, at points between the moraines of the Bighorn epoch and the city of Creede. The fact that these deposits are high above the present valley and not on the intermediate slopes appears to have special significance. If the modern valley had been excavated at the time the San Juan ice there would surely have been remnants of the drift left somewhere on the lower slopes in protected spots. Just east of the San Cristobal quadrangle this ancient glacial drift is found nearly 2,000 feet above the present valley. Near Creede the deposit is represented by a scattering of bowlders on the ridge just west of the city. These bowlders have probably been reworked and let down somewhat from the position where they were left by the ice. This older drift is not difficult to recognize in the Rio Grande Valley because of the presence in it of crystalline rocks which must have come from the western margin of the San Cristobal quadrangle or from still farther west. The probable form of the San Juan glacier which advanced down the Rio Grande Valley is indicated on Fig. 3.

At the northwest margin of the range the San Juan glacial drift is associated with the valley of the Uncompahgre River which has its source in the mountains south from Ouray. In its upper course the stream flows through a deep canyon cut between some of the highest mountain peaks of the range, but below Ouray the valley widens and above the broad open floor there are terrace remnants characteristic of the valleys in the plateau country bordering the mountains.

Between Ridgway and Montrose the western slope of the valley is formed by the eastern escarpment of the Uncompahgre plateau. To the east, in the low country, the valley is bordered by low hills and mesas. Ten miles due west from Ridgway the divide between the Uncompahgre and the San Miguel rivers is marked by a line of hills rising above the surrounding plateau surface. The highest of these is Horsefly Peak, a hill composed of Mancos shale held up above the surrounding mesa by a protective capping of a heavy bowlder deposit. As noted by Howe and Cross[1] Horsefly Peak and the hills adjacent to it

> are covered so thickly by pebbles, bowlders, and blocks of volcanic material, often 10 or 15 feet in diameter, that in many places the hills have the appearance of being entirely composed of the detritus. The material was derived almost entirely from known late volcanic flows and breccias of the mountains and appears to have been once partly rounded or subangular, but has been much modified in form through weathering. In addition to the late volcanic rocks, there is a little granite and Algonkian quartzite, probably derived from an early Tertiary conglomerate, which in age immediately precedes the volcanic rocks and which is known to occur in the mountains to the south and east. The mass of the hill beneath the gravel is composed of Cretaceous shales resting on the Dakota sandstone, which forms the capping formation of the plateau, and it is probable that many of the moraine-like hillocks and depressions resembling kettle-holes may be due to the uneven erosion of the shales, but in a few places it is possible that true morainic forms exist, although much modified by erosion and weathering.

Similar deposits occur on West Baldy, 5½ miles south of Horsefly Peak, as noted by Howe and Cross, as well as on South Baldy, a few miles to the southeast, and on several hills rising above the level of Hastings' Mesa to the southwest, as shown in Fig. 4. At each of these localities these deposits suggest by their physical and lithological heterogeneity, by their lack of assortment, subangular stones, by huge bowlders up to 25 feet in diameter, and topographic situation that they are of glacial origin. At one locality over an area of about one square mile there is an old morainic topography, and on Horsefly Peak, West and South Baldy striated stones were found. The striae were all found on surfaces that had not been exposed. Most of the striated stones found were small, but on the underside of a huge bowlder on South Baldy, Professor R. D. Salisbury found a remarkable example of a smoothed, polished, and striated surface. There is no question but that the material is of glacial origin.

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[1] *Bull. Geol. Soc. Am.*, XVII (1905), 261–62.

Landslides have frequently affected the disposition of these earliest glacial deposits, but this later topography can be easily distinguished from the morainic topography. Scattered over the mesa surface to the east and northeast of Horsefly Peak there are several small deposits of bowlders which point to a former much more widespread deposit of glacial drift.

On the eastern side of the Uncompahgre Valley between Cow Creek and Cimmarron Ridge there are extensive bowlder deposits which have now been referred to the San Juan epoch of glaciation. The portion of this deposit which lies within the Ouray quadrangle has been mapped in the Ouray folio as "earlier moraine" and the same formation extends some distance north of that quadrangle. The deposit is similar to that at Horsefly Peak as far as the size and assortment of the bowlders is concerned, although no quartzites and very few granites were observed there. In one locality on Burro Creek a good section of the bowlder-gravels is exposed and here it is seen that the bowlders are imbedded in a typical bowlder-till.

The components, arrangement, and topographic relations of these several deposits on the north side of the range show that they are remnants of a once more widespread formation which covered a large area in this vicinity. The size and distribution of the materials composing the detritus, the fact that these huge bowlders have been transported many miles, and the glacial markings which some of them bear, point unmistakably to their glacial origin.

The position of these drift deposits, on and near the divides between the present drainage channels, and in front of the present mountain spurs, is in sharp contrast to that of the deposits referred to the Uinta and Bighorn glacial epochs. The latter are restricted to the present valleys and are much nearer the present mountain front. It is therefore evident that these outlying and somewhat scattered bodies of drift must be the work of the earlier and more widespread body of ice which has been referred to as the ice of the San Juan glacial epoch.

The great age of the deposits made during the San Juan epoch is, in a general way, attested by their location on the present divides. Hundreds of square miles of surface, between the mountains and the remnants of San Juan drift, have been entirely cleared of glacial débris, and notable canyons now separate the mountains from the isolated hills capped with San Juan glacial bowlders. Furthermore, some of the bowlders in the San Juan drift are from formations which formerly covered the neighboring mountains but have since been removed from all but a few summits. It is quite certain that these formations were much more widespread at the time of the formation of the San Juan ice and, therefore, that the relief in the mountains was much less than at present.

On the southern side of the range in the Piedra Valley drift of this oldest epoch which came from the mountains at the head of Middle Fork and the main Piedra River is now separated from the mountains by the 1,000-foot canyon of the Huerto River which must be entirely of post-San Juan age. The deposits capping Horsefly Peak and West Baldy are now separated from the mountain front by the drainage of Dallas and Leopard creeks which have lowered their channels far below the surface upon which the ice of this epoch rested. South Baldy and other elevations to the west that are capped with San Juan drift are distinctly separated from the main mountain front by erosion depressions.

In general, erosion since the San Juan glacial epoch has been so complete and widespread that only those deposits which were situated where conditions were most favorable for their preservation have escaped removal. This is well illustrated by the conditions at Horsefly Peak. Although the drift there has been responsible in large measure for the preservation of the shale upon which it rests and for the existence of the peak, the shale in turn has been protected from erosion by the underlying Dakota sandstone which forms the surface of most of the Uncompahgre plateau and has delayed the headward growth of valleys that threaten the Horsefly Peak region. Erosion into the Dakota sandstone is still in the stage of extreme youth, while nearly all of the overlying Mancos shale has been removed. This most remarkable plateau of the San Juan district is a very fortunate place for the preservation of a drift deposit through long periods of erosion, and it is on just such surfaces that other remnants of this ancient glacial formation are most likely to be found.

Still more striking are the facts which may be deduced from the composition of the drift bordering the Uncompahgre Valley. The bowlders, as already noted, are almost entirely composed of late volcanic rocks with only a very few fragments of quartzitic and granitic rock. The latter are believed to have been derived from the bowlders of the Telluride conglomerate and their extreme rareness is in sharp contrast to the great proportion of similar bowlders found in the Uinta and Bighorn drift of the Uncompahgre Valley. The quartzites of the two more recent glacial deposits are in the main derived from the Uncompahgre quartzite of the Uncompahgre canyon south of Ouray, and the absence of bowlders from this formation in the drift of the San Juan epoch indicates that this formation was not exposed in this part of the range at the time of the San Juan glaciation. At the present time the Uncompahgre quartzite is found outcropping on the canyon walls, 2,000 feet above the stream. There must have been a canyon deepening at this point of at least that amount since the glaciation responsible for drift on Horsefly Peak and beneath Cimmarron Ridge.

Again, the relation of the San Juan drift near Creede to the broad upland valleys above the present canyons there suggests the extreme age of this earliest of known Pleistocene deposits in the western mountains. The relief of the mountains during this stage must have been very much less than at the present time and the topography must have been characterized by broad, shallow, mature valleys with low interstream ridges in marked contrast to the rugged peaks, the sharp divides, and the narrow canyons of the present time. The physiographic development of the great scenic features of the San Juan area is therefore largely the work of inter- and post-glacial times.

The valley deepening in the San Juan Mountains since the San Juan glacial epoch must be reckoned in thousands of feet. The Uncompahgre interglacial epoch between the San Juan and Bighorn glaciations must have been several times as long as the Animas interglacial epoch. It is probable that the long period of erosion following this earliest glaciation was not a time of continuous valley deepening. In addition to the depositional interval during which certain high mesas were mantled with bowlders there may have been other epochs of glaciation which intervened between the glaciations of the San Juan and Bighorn epochs but which have left no permanent record. The Uncompahgre interglacial epoch may not be in a strict sense an *interglacial* epoch but may include one or more glacial epochs as well.

Comparing the deposits of these three known glacial times in the San Juan district it is at once seen that the earliest is in striking contrast to the two younger ones in point of area covered and distance from the mountain front attained by the ice. The glacier which extended north from the range to some distance beyond Horsefly Peak should probably not be called a valley glacier. The San Juan ice on the south side of the range was not restricted to a valley, for it extended some distance beyond the mountain front as a great piedmont glacier. The wide area covered by ice at this time seems to indicate a period of far more extensive glaciation than that of the two epochs of valley glaciers, and it is probable that during San Juan glacial epoch much of the mountain country was covered by an ice-cap, while piedmont glaciers deployed over the surrounding plateau lands.

Relation of glacial epochs to physiographic stages in the history of the San Juan mountains.—The physiographic stages in the late history of the San Juan mountains have been worked out in some detail[1] on the south and southwest sides, and in part on the north

[1] W. W. Atwood, *Jour. Geol.*, XIX (1911), 449–53.

side of the range. In outline these stages are as follows: At some time subsequent to the deposition of strata of Wasatch (Lower Eocene) age, and probably near or at the close of the Tertiary period, the San Juan region was reduced to an almost base-leveled condition. Only a few elevations remained as monadnocks above the peneplain upon which streams with gentle gradients were depositing at places a thin mantle of remarkably well-rounded and waterworn quartzite and jasper pebbles. The cycle of erosion which developed this extremely old-age topography was closed by a general uplift in the district, which was emphasized in the San Juan dome. Dissection of the peneplain began in the uplifted dome area and resulted in the formation of great alluvial fans, composed of bowlders as well as gravels, upon the peneplain fringing the dome. At the same time rejuvenation was working upstream across the broad plateau and as soon as this headward erosion had reached the margin of the dome the growth of the great alluvial fans ceased and their dissection began. Remnants of this gravel- and bowlder-capped peneplain are now found as the summit elevations in the mountains and upon the neighboring plateaus.

Below the peneplain level there are other broad bowlder-capped mesa-like forms which appear to represent the base to which the streams worked when the peneplain was first dissected. The bowlder-capped mesas noted in the paragraph descriptive of the Uncompahgre interglacial epoch are typical of this bowlder-mesa stage in the dissection of the area. Another uplift associated with the more or less continuous growth of the mountains deformed the graded surfaces of the bowlder-mesa stage, again rejuvenated the streams, and opened another cycle of erosion. The surfaces to which the streams then worked have been referred to in the studies on the south side of the range as the graded surfaces of the Oxford stage. Beneath these surfaces the streams have cut comparatively narrow valleys.

The problem of the relationship of the epochs of glaciation to the stages in the erosion history of the range is of special interest. The available data make it possible to present a tentative or working hypothesis for the solution of this problem.

On the northern slopes of the range between Cow Creek and

Cimmarron Ridge, and on the west of Horsefly Peak, the San Juan drift lies above and beyond fairly extensive bench surfaces covered with bowlder-gravels. These surfaces slope gently toward the Uncompahgre River. Their extreme evenness, as well as the size and assortment of the bowlders capping them, attest to their origin as graded surfaces of erosion upon which a bowlder deposit was made. These bowlder-covered surfaces are below, and appear to be cut into, the drift deposits and therefore are younger than the drift. It is believed that these surfaces are remnants of the graded surfaces developed during the bowlder-mesa stage of mountain dissection. If this is true the glaciation of the San Juan epoch was one of the incidents which took place during dissection of the late Tertiary peneplain previous to the development of the bowlder-mesas.

On the south side of the range the Bighorn moraines and outwash deposits are found adjacent to the graded surfaces of the Oxford stage near the Pine, Florida, and Animas valleys. The relations there indicate that the Oxford stage of mountain dissection was soon followed by the glaciation of the Bighorn epoch. During the Uncompahgre interglacial epoch the graded surfaces of both the bowlder-mesa and Oxford stages were developed. The Animas interglacial epoch was not of sufficient duration for the formation of great erosional features, but was brought to a close by the Uinta glaciation before the streams had again reached a temporary base level.

Comparison of the glaciation in the San Juans with that of the adjacent mountains.—A comparison of the glacial deposits now known to exist in the San Juan mountains with those reported from the neighboring mountain ranges of Colorado and Utah, as referred to in the opening paragraphs of this paper, shows that the two glaciations of those ranges, known as the "earlier" and "later," are to be correlated with the Bighorn and Uinta epochs as above defined. In the mountain ranges from which two glacial epochs have been reported it is noted that the moraines of each epoch are limited to the immediate valleys and that the earlier is only slightly more extensive than the later. They bear the same relation to each other and to the topographic features of each region as that which characterizes the Bighorn and Uinta deposits of the San Juan mountains.

On the other hand, certain outlying bowlder deposits, recognized in the Uinta mountains by the senior author and in the Bighorn and Sawatch ranges by other observers, which there suggested a third and earlier glacial epoch, would appear to correspond closely to the deposits made by the ice of the San Juan epoch. Like the drift of that stage, as recognized in the San Juans, the bowlder-gravels noted in these ranges occur in patches at some distance from the mountain front and situated on or near divides. It is probable, then, that drift of the San Juan glacial epoch will be recognized in other ranges of the western Cordillera, and it is hoped that additional data may be secured bearing on the amount of Pleistocene and post-Pleistocene erosion in this portion of North America.